Bulletin No. 23.—W. B. No. 186.

U. S. DEPARTMENT OF AGRICULTURE,

WEATHER BUREAU.

FROST:

WHEN TO EXPECT IT AND HOW TO LESSEN THE INJURY THEREFROM.

Prepared under direction of WILLIS L. MOORE, Chief of Weather Bureau.

BY

W. H. HAMMON,
PROFESSOR OF METEOROLOGY.

WASHINGTON:
WEATHER BUREAU.
1899.

Bulletin No. 23.—W. B. No. 186.

U. S. DEPARTMENT OF AGRICULTURE,

WEATHER BUREAU.

FROST:

WHEN TO EXPECT IT AND HOW TO LESSEN THE INJURY THEREFROM.

Prepared under direction of WILLIS L. MOORE, Chief of Weather Bureau.

BY

W. H. HAMMON,
PROFESSOR OF METEOROLOGY.

WASHINGTON:
WEATHER BUREAU,
1899.

LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Weather Bureau,
Washington, D. C., November 10, 1898.

Hon. James Wilson,
Secretary of Agriculture, Washington, D. C.:

Dear Sir: I have the honor to transmit herewith a paper on the subject of frost, prepared by Mr. W. H. Hammon, forecast official, San Francisco, Cal., with request that it be printed as a bulletin of the Weather Bureau.

Mr. Hammon has devoted much thought to and made careful study and investigation of this subject. The paper is a revision of one formerly prepared by him and issued as a bulletin of the Weather Bureau. It was received with much favor, having been published by the California State Board of Horticulture. The urgent demands for a reprint that have been received have prompted a revision of the pamphlet, with a view to republication. An edition of five thousand is recommended.

I am, very respectfully,

Willis L. Moore,
Chief of Weather Bureau.

Approved.
James Wilson,
Secretary.

TABLE OF CONTENTS.

	Page.
Preface	7
Formation of frost	9
Methods of frost prevention	10
Methods for retarding radiation	11
Raising the dew-point	14
Portable smudge fires	15
Steam and vapor protection	18
Adding heat to the air	20
Directly heating the air by means of fires	21
Report of experiments in frost protection made by the Riverside Horticultural Club	22
Orchard protection	27
Draining cold air from region needing protection	28
Mixing air so as to prevent cold air from sinking to the surface	29
Appendix No. 1.	
Use of the sling psychrometer	34
Dew-point table	36
Appendix No. 2.	
Injurious temperatures	37

PREFACE.

In December, 1895, a freeze occurred in the citrus region of southern California which very appreciably reduced the orange output for that season. The temperatures, even in the coldest localities, were so little below the point of safety that it seemed as if the loss might have been avoided had the orchardists been familiar with the principles of frost protection. With the purpose of furnishing this information the writer prepared, in January, 1896, a short article on frost protection, which was published by the Department of Agriculture in Weather Bureau Bulletin No. 86.

Since the publication of this bulletin the subject of frost protection has received much attention, especially in California. Many orchardists made experiments along the line suggested in this bulletin. The agricultural and even the daily press gave liberal space to the discussion of these subjects. Many devices and methods were proposed and some were tested. So much was accomplished in the spring of 1896 that the California State Board of Horticulture deemed it advisable to publish a more extensive bulletin than Weather Bureau Bulletin No. 86, embodying these experiments and suggestions. This was accomplished in Bulletin No. 70 of that society, published in the autumn of 1896, probably the most complete bulletin written on this subject that had then been published in this country.

However, experiments, made since the publication of this pamphlet, render a modification of many of its statements necessary. Too great prominence was given to certain methods and too little to others. Important exceptions have been found to some general rules. Consequently it has been deemed advisable to publish a revised edition of this bulletin, incorporating in it the lessons gained from more recent experiments.

While the methods advocated are mainly the result of experiments conducted in California orchards, still the principles are capable of much broader application, and the rules laid down for protecting these orchards will prove generally useful with such modifications as local topography and atmospheric conditions may render advisable.

FORMATION OF FROST

Before proceeding to a consideration of methods of preventing injury by frost, it is essential that the conditions under which it forms be quite thoroughly understood.

The two principal methods by which plants lose their heat are *convection* and *radiation.*

The movement of the air is continuously bringing new particles of it in contact with the plants, and if the air be cooler than the plants it will take from the plants a portion of their heat, until both air and plants are at the same temperature. This is known as *convection*, and is very effective on windy nights when a cold wave is approaching, and the breeze is continually bringing new portions of the atmosphere about the plants. We can hardly attribute to this process the great loss of heat on the quiet, clear nights when frosts mostly occur; for on such nights the plants are usually colder than the surrounding air, and any mixing of the air tends to raise their temperature.

The chief method by which plants lose their heat on calm, frosty nights is by *radiation.* By this term is meant that peculiar process by which heat escapes from an object and passes through the surrounding space in direct lines in the same way that rays are emitted from a source of light. Heat, lost by radiation, does not appreciably warm the air through which the ray passes, but its effects are manifest at any surface which obstructs the passage of the ray.

The surface of the earth is continually losing heat by radiation into space, but during the day it usually receives heat from the sun more rapidly than it loses it by radiation, and consequently it grows warmer. At night, however, heat from this source is cut off and the continued radiation causes the temperature to fall.

Under favorable conditions this fall continues until condensation of vapor begins. Aqueous vapor, although invisible, is always present in greater or less quantities in our atmosphere, and can always be condensed into water if the temperature be sufficiently lowered. If the condensation takes place at temperatures below the freezing point of water, the moisture is deposited in the form of frost.

The heat given off by the condensation of vapor is enormous. The condensation of enough vapor to make a pint of water will evolve enough heat to raise more than five pints of water from the freezing to the boiling point. All this heat must be lost by radiation in order that the formation of dew may proceed or the temperature fall. It is, therefore, evident that when condensation begins, the heat evolved by this means practically prevents further cooling.

The temperature at which condensation begins is called the "dew-point," and varies with the amount of moisture in the air, being higher the greater the amount of moisture present. It is always constant for the same amount of vapor.

Radiation takes place most rapidly when there is nothing to obscure the sky. Clouds or any other obstruction act as a screen in retarding it. Even water vapor, while invisible, has a very appreciable effect in retarding it. It takes place more rapidly from the surface of plants than it does from the air about them, so that on still nights these surfaces are frequently cooled several degrees below the temperature of the surrounding air.

One more principle should be considered in the study of the conditions under which frost forms, and that is the increased density of the air as its temperature is lowered. Owing to this principle, the air, on calm nights, arranges itself in accordance with its density. The heavier cold air rests on the surface and surrounds the plants and trees, thus increasing their liability to injury. On still nights this fact is often very manifest. Frequently a thermometer close to the ground will read 5° or 10° lower than one 8 or 10 feet higher. This principle causes the air on slopes, as it becomes chilled by radiation, to flow down into the valleys, where it accumulates, thus frequently causing severe frosts in the lowlands, while the hillsides remain uninjured. It is for this reason that frost does not so readily occur on windy nights, since the wind mixes the air to a more uniform temperature throughout and causes that near the ground to be warmer than it would be otherwise.

Therefore, the conditions favorable to frost formation are: (1) Clear sky, because radiation of heat is rapid under these conditions; (2) dry air, because with dry air, cooling by radiation will continue to a lower temperature before it is checked by the heat given off by condensation; (3) still nights, because under these circumstances the air arranges itself in layers according to its density, and the colder, denser air collects near the surface.

METHODS OF FROST PREVENTION.

From a study of the foregoing principles under which frost forms, it would seem that there would be the greatest probability of success in preventing frost or diminishing its severity by working along the following lines:

I. Diminishing the radiation of heat.

II. Raising the dew-point by adding moisture to the air, and thus making sensible the latent heat of condensation at a temperature above the danger point.

III. Adding heat to the air.

IV. Draining the cold air away from the section which needs protection.

V. Mixing the air so as to prevent the cold air from sinking to the surface.

It is believed that all efficient methods of protection which have been devised are embraced under one or more of those classes. The methods will be grouped in accordance with the above classification

I. METHOD FOR RETARDING RADIATION.

Since radiant heat is transmitted in straight lines, the erection of any screen between the plants and the open sky tends to intercept the rays and either reflect them back toward the earth or absorb them, thus raising the temperature of the screen which cheeks the loss of heat, for the screen itself now becomes a radiating surface and returns a portion of its heat to the earth.

Any substance which tends to obstruct the passage of heat rays forms a more or less effective screen for checking radiation.

Glass screens.—In greenhouses and hotbeds advantage is taken of the peculiar property of glass which allows the heat rays of the sun to pass through it, and is almost impervious to the *dark* heat rays from the earth and plants. This is one of the most perfect screens possible, since it not only prevents the loss of heat by radiation, but receives and retains the heat from the sun. The expense precludes its adoption, except for the protection of valuable plants and flowers.

Screens of other solid materials have been quite extensively used in protecting vineyards and citrus groves where intense cultivation is practiced, and where the location of the groves, near an excellent market, admits of profit even with expensive methods of cultivation.

Cloth screens.—In Italy and portions of France screens made of muslin strung on wires stretched on poles above the tops of trees or vines have been used extensively. These screens are drawn on nights when frosts are probable and pushed back during the day. When the season has advanced so as to preclude further danger, they are taken down and stored. Of course, such a plan could be operated only on a very limited scale, and would then be expensive. This plan has been recently successfully tried in the orange groves of southern California.

Lath screens.—During the past few years screens made of laths fastened to ordinary telephone wire (the spaces between them being about the width of the laths) have been extensively used in Florida. These are spread over a frame erected above the trees or plants. The screens serve not only as a fair protection from frost, but also as a shade from hot sun. When no longer needed they can be rolled up and stored away for preservation. At first thought it would seem improbable that a screen covering only half the space (the spaces

being as wide as the laths) would afford much protection; but, when it is considered that laths have considerable thickness, it is plain that, while only one-half the vertical rays are screened, those inclined between the vertical and horizontal are partially intercepted by the edges as well as the faces of the laths. As a matter of fact, about three-fourths of the sky is screened by this means.

By placing the laths in north and south directions, the direct rays of the morning sun are completely cut off from the orchard, which admits of the temperature rising slowly. This greatly reduces the liability of injury to the plants. Dr. B. T. Galloway, in the U. S. Department of Agriculture Yearbook, 1895 (p. 145), thus explains why frozen plants are less likely to be injured when warmed slowly:

Under the influence of cold, the water in the cells escapes, and may be frozen either in the spaces between the cells or on the surface of the leaf, stem, or whatever the part may be. As the temperature rises, this frozen water may again be taken up by the cells, and in such cases little or no injury results. If for any reason, however, the cells are not able to regain the water withdrawn by the cold, injury or even death may result. In many cases the rapidity with which the ice is thawed has a marked effect on the ability of the cells to gain their normal condition. If the thaw is gradual, the water is furnished no faster than the cells can absorb it, and equilibrium is, therefore, soon restored, the chemical processes which were checked during the freeze are resumed, and the plant soon regains its normal condition. With a rapid thaw, however, the cells are not able to take up the water as fast as it is furnished, and as a result chemical decomposition sets in, and death follows. Death in this case is essentially the same as that which results from drought. The cell loses water to such an extent that it is not again able to become turgid, and as a result it finally withers and dies.

Other methods.—While the foregoing methods are quite efficacious in preventing injury, still the expense is entirely too great to admit of their adoption for general use in orchards.

Strawberries and other low plants are frequently protected by covering them with straw or other loose substances.

Frequently young potato plants are saved by plowing a furrow alongside and allowing the dirt to bury them.

Cranberry growers in the marshes of Wisconsin flood the marshes when frost is expected. In this case the protection is probably due, for the most part, to the high specific heat of water, as only portions of this land are submerged.

Smudge fires.—Since radiation is so reduced as to prevent the formation of frost on cloudy nights, many have thought that an artificial obscuration of the sky by means of dense smoke would be an excellent means of protection. The efforts of this character which have been made have resulted in decidedly varying success. In the wheat fields of the Dakotas, excellent protection was obtained, while the experience of orchardists in Florida and southern California has not shown such a uniform success.

Since it was supposed that the protection resulted from the obscuration of the sky by means of smoke, the best protection was expected from the use of that fuel which would produce the greatest smoke.

In the Dakotas the best and most convenient material at hand was the straw of the previous year's crop, which had been left in the fields all the winter and through the rainy spring, until it was quite thoroughly soaked with water.

In southern California and Florida straw was scarce, and where it could be obtained it was much drier than that used in the Dakotas, consequently tar, crude petroleum, and other similar smudge materials were substituted; but the results have not been, as a rule, satisfactory, although the smoke was equally dense. However, quite successful results were obtained by Mr. Buck, Mr. La Rue, and others in the Vacaville and Sonoma sections by burning damp stable manure in sacks scattered through the orchard.

After considering the question, the writer was convinced that the protection of the northern wheat fields must be due to something besides the checking of radiation by the cloud of smoke, for the heat which is radiated from the earth to the cloud is absorbed by the cloud and not reflected. Consequently, unless the air is almost perfectly calm to a considerable elevation, the heat is carried away as the smoke drifts off with the wind before much is radiated by the cloud of smoke back to the earth.

Damp smudge fuel preferable.—It was observed that, as a rule, whenever damp fuel was used, the efforts at protecting were more successful than at other times. In the case of dry smudge material, the heat of the fire raises the temperature of the air about the burning fuel to hundreds of degrees above the surrounding air. It is consequently greatly expanded, and its density diminished so that it rapidly rises and the neighboring air flows in to take its place. This also is, in turn, heated and escapes upward, carrying the heat and smoke of the fire with it. On reaching an elevation considerably above the trees, it is blown away more or less rapidly by the almost constant circulation of air at such an elevation.

When damp fuel is used, a considerable portion of the heat of the fire is expended in evaporating the water in the fuel, and the consequent upward draft of the fire is lessened by this amount.

The amount of heat consumed in evaporating water is very considerable. The evaporation of a quart of water would necessitate the expenditure of as much energy as would be needed in raising the temperature of the air 25° throughout a space 10 feet square and deep.

It is evident from this fact that the upward draft, which was so marked in the case of dry fuel, is greatly diminished when damp fuel

is used; consequently, the smoke remains nearer the surface, where the trees interfere with the movement of the wind and tend to retain the smoke, thus increasing the protection.

Further, Tyndall has proven that vapor itself, even while invisible acts as a barrier in retarding radiation, and if it condense rapidly enough it will cause the small particles of water thus left suspended in the air to form a cloud or fog, which will obscure the sky and prevent radiation.

However, by far the principal cause of the protection obtained from the wet smudge properly belongs to the second class of methods namely:

II. RAISING THE DEW-POINT.

By adding moisture to the air and thus making sensible the latent heat of condensation at a temperature above the danger point.—As mentioned above, when damp fuel is used a considerable portion of the heat produced by the fire is expended in evaporating the water in the fuel. The vapor thus formed is invisible and has all the properties of a gas, and quickly distributes itself throughout the surrounding space almost as rapidly as air will expand to fill a vacuum, for it is a property of gases that each will occupy a given space in almost the same manner as it would if the others were not present. But as the vapor expands into the surrounding cooler air its temperature is lowered and, unless the air be very dry, a portion of the vapor is condensed, forming a visible fog or mist. Now, all the heat which was consumed in evaporating the water again becomes sensible upon its condensation, and tends to raise the temperature of the surrounding air. The heat thus set free will be in great part confined to the particles of water composing the fog, which are too dense to rise, and thus they will tend to prevent the escape of the heat, and at the same time they are so small that they float in the air as fog, with hardly a perceptible tendency to fall.

The tendency is, therefore, to trap the heat produced by the fire and distribute it throughout the space near the surface which needs protection. The excessive heat about the fire which, with dry fuel, produces the wasteful upward draft, is, in this instance, utilized in evaporating the water in the fuel. The vapor then, by the operation of its gaseous property, distributes itself quickly throughout the surrounding cooler space, where, in condensing, it sets free its latent heat, warming the region, and, by the density of the fine particles of water thus warmed, the heat is retained near the surface.

After a considerable study of various methods of protecting orchards against frost which have thus far been made public, the writer has become convinced that those which depend for their success upon this principle (II) are generally the most efficient. In very dry climates, however, where the dew-point at times of danger

is 10° or more below the temperature of the air, this method is inefficient since the vapor does not condense in sufficient quantities to protect, and owing to the vapor being lighter than air, it escapes upward and the heat necessary for its formation is lost.

Many methods which involve this principle have been suggested and tried, two of which have already been mentioned, namely:

Fires of damp straw and stable manure.—Have the fuel, in small piles, distributed throughout the orchard in advance; the more numerous the piles the better. With the same amount of fuel the best protection is obtained from small and frequent fires, since, with small fires, the upward draft is reduced to a minimum, and the more frequent the fires the more uniform will be the distribution of heat.

Sacks of manure.—A decidedly preferable method is to pack damp stable manure in common grain or burlap sacks, by which it can be conveniently handled. They should be distributed through the orchards in rows about 100 feet apart, and about 50 feet between sacks in each row. When it is found necessary to protect, a small amount of coal-oil is poured upon each sack and ignited. It is usually unnecessary to fire more than every second or fourth sack, the remainder being left for later occasions. These sacks will burn with a smoldering fire for several hours.

The amount of heat which is set free by burning one sack of manure weighing about 50 pounds, and condensing the vapor near the surface, would be sufficient to raise the temperature 20° in a space 75 feet square and 25 feet deep. If one-fourth of this heat remained within the region needing protection, which seems to be a reasonable estimate, ample protection would be obtained for almost any ordinary conditions.

Bales of wet straw.—Mr. T. A. Morrison, of Riverside, Cal., suggested the use of a similar plan, in which bales of wet straw were substituted for manure. This plan has been tried with fair success. One-hundred pound bales were cut in four pieces, a tie wire being left about each piece, and, if properly dampened, will burn with but little care, causing a small smoldering fire.

Prunings.—The prunings of the trees, which are usually removed shortly before the period when frosts are likely to do their greatest injury, are excellent smudge material, and should always be preserved for this use. They should be piled in open spaces throughout the orchard or vineyard, and burned at times when protection may be needed. The best results will be obtained from as small fires as will result in burning the prunings.

PORTABLE SMUDGE FIRES.

A number of excellent devices have been tried, in which the fires

were built upon some vehicle by which they could be moved about the orchard. The advantages of this plan are several:

First. The fire can be moved to the section where most needed, generally along the windward side of the orchard.

Second. The loss of heat by an upward draft is almost entirely prevented, since the fire does not remain in one position long enough to establish such a draft. On this account much larger and, consequently, fewer fires, with equal efficiency, are possible.

Third. There is a much more uniform distribution of heat throughout the orchard.

The Fleming Fruit Company's process.—One of the first to adopt this plan was the Fleming Fruit Company, of Visalia, Cal., the manager of which thus describes his method:

We built wire frames (chicken-yard fencing) on our low truck wagons, stretching them from four wagon stakes and heaping over with wet manure. Dirt was then thrown on the wagon beds to protect them, and pots of burning tar were set underneath the straw roof. A barrel of water on the wagon was used to keep the straw wet. These wagons were driven about and did the best work, as they could go wherever most needed. The smoke and vapor were carried to the rear as the wagon moved, and, being carried at once out of the rising heat, fell close to the ground in a long, white trail. At daylight our whole 400 acres of orchard were covered with a white fog, extending from the ground to about 20 feet high.

They also used similar fires as stationary smudges, the wire netting being stretched between four stakes driven in the ground, and a similar plan has been since experimented with by Meacham Brothers, of Riverside, Cal. These latter proved much less efficient.

The plan of the Rio Benito Orchard Company.—A modified form of the Fleming process was used with excellent results by this company at Biggs, Cal. In this case rough sleds were constructed at a cost of less than $2 each. The runners were of 2 by 4 scantling, which were connected by a few boards about 4 feet long. Upon these dirt was piled to hold the pot of burning tar. The four upright sticks were spiked to the runners, the tops of which, about 18 inches above the bed of the sled, were connected by strips of inch boards 4 to 6 inches wide. To these strips the chicken-wire netting was attached. This rude box or screen supported the wet straw or manure used as smudge material. Four of these sleds, two wagons rigged after the Fleming plan, and about 500 sacks of manure were found sufficient protection for an orchard of 300 acres during each night of the severe April frost of 1896. The orchard was successfully protected during six successive nights of severe frost, at an expense of less than 1 per cent of the value of the crop undoubtedly saved by this means.

This device can be made much more efficient by supporting the center of the screen by an arch of heavy, stiff wire passing diagonally from runner to runner and forcing up the bottom of the screen so as to cause it to present a concave surface to the fire, thus causing more

of the heat to pass through the smudge material and less to escape upward about the sides of the screen.

Mr. Priestly Hall's device.—Mr. Priestly Hall has made a much more efficient form of sled, operating under the same principle. Upon a sheet-iron bed of a sled he has placed a small fire-box, consisting of a grate 4 or 5 inches above the bed of the sled, over which pass iron rods bent in the form of an arch, leaving a space for the fire about 14 inches in diameter. This fire-box is inclosed in a large corrugated iron box, which has the bed of the sled (about 3 by 4 feet in size) for a bottom, and sides 30 inches high. A door is made in the front of the corrugated box, to admit fuel to the fire. The box is kept filled with wet straw or manure and a fire is maintained in the fire-box when the machine is in operation.

The Howard method.—Mr. R. H. Howard, of Riverside, Cal., has devised a somewhat similar plan, which undoubtedly will be found very efficient. The fuel used is crude petroleum, supplied to the burner from a tank on the wagon or truck containing the apparatus. Over the burner is placed a large wire basket, containing mineral wool, which is kept saturated with water supplied by a tank, also placed upon the wagon. Wet straw or manure could also be used, if desired. The apparatus can be driven about the orchard where most needed. The burning coal-oil gives off a dense smoke, while the wet mineral wool will furnish a vast amount of surface from which evaporation can take place, and at the same time the material will not be consumed. Mr. Howard suggests the use of somewhat similar devices for stationary evaporators placed in various portions of the orchard.

Mr. George F. Ditzler's machine.—A number of more or less expensive mechanical appliances have been devised which depend upon this principle (II) for their success in protecting. Undoubtedly, among the best of these should be mentioned that of Mr. George F. Ditzler, superintendent of the Rio Benito orchards at Biggs, Cal. The machine consists of a large sheet-iron tank, 3 or 4 feet square and deep, which is mounted upon a truck. About 6 inches from the bottom of the tank a wire screen or grate is erected. Through a hole in the tank beneath the screen a blast is admitted, which is produced by a revolving fan similar to those used in blacksmith forges. This is operated by a sprocket chain and wheel attached to the wheel of the truck. A water cask and force pump, operated by the movement of the wagon, complete the outfit. In operation, a little tar or other fuel is placed upon the grate and ignited, and the tank is then filled with wet straw or manure, when the machine is put in motion. The blast thus produced causes an intense fire, which will burn the wettest of fuel, and all of the heat of the fire must pass up through the 3 feet of wet material before it can escape into the air. By this means, almost the entire heat is consumed in evaporating water, which

quickly condenses after escaping from the tank, and forms a dense fog or mist. That the heat of the fire is thus expended in evaporating water is evidenced by the fact that the air which escapes from the tank, charged with moisture, is but little warmer than the surrounding atmosphere. While the machine is in motion, water is continually pumped from the cask and discharged from small holes about the top of the tank upon the fuel. The machine is driven forward and back between the rows of trees in the orchard. It is said that one such machine will evaporate 100 gallons per hour, which, under the conditions it produces, should protect about 50 acres. The fog thus formed in the orchard is so dense that the driver frequently has to go ahead and lead the team, since, from the truck, he can not see to drive it.

Probably no greater protection has been obtained from the burning of the same amount of fuel than by this machine, since but little, if any, of the heat is wasted; however, it may be a question if the gain over that obtained from the use of other portable smudges is sufficient to warrant the increased expense for constructing these machines.

STEAM AND VAPOR PROTECTION.

Many devises have been suggested for protecting by the addition of moisture to the air, besides those involving the wet smudge. A number of these have proven efficient. It would seem, however, as if these plans were not likely to be quite as efficient as the wet smudge, since, with equal evaporation, the wet smudge has the additional protection obtained from retarding the radiation of heat by means of the screen of smoke.

Mr. H. C. Finkle's plan.—Mr. H. C. Finkle, a civil engineer of San Bernardino, Cal., outlined in the Riverside Press, in February, 1896, quite an elaborate plan for protecting citrus groves in southern California. The essential feature of the plan provided for the erection of several large plants for evaporating water from pans over coal-oil furnaces.

The criticism most likely to be made of this plan will be that the upward draft, which must exist with all large stationary fires, will cause a large portion of the heat and the vapor to be carried above the region needing protection.

Further, it is very doubtful if any evaporating pan which might be used would evaporate as much water as would result from the burning of wet straw over the same fire, for the hot gases and air from the fire come in contact with vastly greater surfaces in filtering through the mass of straw than will be encountered in the best of evaporators. The straws thus act as the tubes in a boiler in increasing the surface exposed to the heat.

Such a plant placed at the lowest point in a valley, however, might

be of use in assisting to dissipate the cold air that accumulates in such places, by drawing it into the fire; but in this case a steam-boiler would be preferable, from which the steam might be conducted in pipes for a considerable distance underneath the trees and then allowed to escape from small vents or jets scattered along the pipes.

The evaporating pans previously described were proven inefficient in the extensive experiments conducted at Riverside, Cal., during the winter of 1897–98.

In the preceding methods, heat has been used to add moisture to the air, but several very successful plans do not require that agency. The two most important methods are—

Spraying and irrigating.—By spraying plants and trees with a very fine spray in times of frost, the injury will, in most instances, be greatly diminished. At the Everest Ranch, Riverside, Cal., a portion of the orange grove is protected by sprinklers placed at the top of 50-foot masts, which fill the air with a very fine spray. In nearly every instance the protection has been sufficient, but at times of very severe freezes the accumulation of ice on the trees bruises the tender branches.

Sprinkling a garden before sunrise on a frosty morning has proven of decided value. The water remains on the plants, and is available for absorption by the burst cells of frozen plants as they thaw, and the injury is thus reduced.

In regard to the value of irrigation, Mr. I. H. Thomas, of Visalia, Cal., thus writes to the California State Board of Trade:

> I turned the water on my place a few days before the freeze, and I found it to be a safe remedy against damage by frost. Wherever the water was run, the effect of the frost was neutralized, and the fruit was not damaged. By reason of this precaution I will have a good crop of fruit, while some of my neighbors, who resorted to smudging, lost almost their entire crop. This proves one thing of great value and importance to the fruit-growing industry: that by wetting the soil during these periods of freezing, and causing an evaporation of moisture tempered by the warmth of the soil, the frost is neutralized, and damage averted.
>
> In my orchard, where the thermometer fell as low as 28°, this process resulted in saving my crop from material damage. As a further evidence of a proof of this theory, the Visalia Fruit and Land Company's orchard on St. John's River, for thirty or forty rows nearest the river, as far from the banks as the seepage was sufficient to cause an evaporation of moisture, the fruit was not materially damaged, while back of that, where there was no seepage and where the land was perfectly dry, the crop was ruined.
>
> At another orchard, where they smudged during the frosty period and at great expense, and kept up a cloud of smoke so dense that you could hardly see from one row to another, the damage almost annihilated the crop, except in the case of 40 acres where the water had been turned on a few days before the freeze. On this 40 acres but very little damage resulted. In one spot on the 40 acres that was flooded there was a piece of raised ground that contained 20 or 30 trees, and which the water did not reach. The fruit on the trees of this spot was killed, while, as soon as you came to the trees on the flooded portion, there was no perceptible damage.

This tells a great story, and is not only an additional argument in favor of irrigation in general, but it enjoins the fruit-grower to have his water available early in the spring where he can practice early spring irrigation, and thus not only insure a stronger and more vigorous crop during the critical budding season, but insure also an additional protection against possible danger from late frosts.

In comparing this method with the smudge, it would have been preferable had Mr. Thomas mentioned the character of the fuel used in making the smudge. While there is no doubt about the value of irrigation as a protection from frost, and the same should be used wherever practicable, still the communication of Mr. Thomas leaves a ground for doubt as to the comparative merits of this plan and the smudge. The writer is unacquainted with information from which a satisfactory comparison of these processes can be made, still there is no doubt of the advisability of using irrigation where it is possible, and if this is not found sufficient protection some of the wet-smudge methods should also be employed.

The protection obtained from spraying and irrigating is probably due to very similar principles. It is partly due to the evaporation of the water, which tends to increase the amount of moisture in the air, so that condensation will take place at a higher temperature.

However, the greatest amount of protection is probably due to the third principle of protection, namely:

III. ADDING HEAT TO THE AIR.

This results from the high specific heat of water. Owing to this property, about six or seven times as much heat is required to raise the temperature of water 1° as is necessary to change the temperature of most other substances by a like amount. Consequently, in cooling, six or seven times as much heat must be withdrawn from a mass of water as from other substances to produce the same fall in temperature. Dry soil will, perhaps, on an average, absorb 30 per cent of its weight of water, which, if at the soil temperature, will contain twice as much heat as the soil itself. Therefore, as radiation cools the earth's surface at night, this saturated soil will have three times as much heat to radiate as would be available were the soil dry. Its rate of cooling is therefore much slower, and the danger of frost is thus greatly decreased.

This effect is probably still further augmented by the water increasing the conductivity of the soil, so that, as the surface cools by radiation, heat from the soil beneath is brought to the surface more rapidly, thus making available a still larger amount of heat.

Undoubtedly, experiments as to the relative conductivity of wet and dry soils have been made, but the writer has not the data at hand for examination, and therefore can not make an estimate of the benefit to arise from this principle; it is evidently considerable.

While irrigation is undoubtedly a valuable protection, there is one

caution that must be considered in its use. Plants are much more easily damaged when full of moisture and sap, and when growing rapidly, than when drier and in the semi-dormant state in which they remain during the winter. Therefore, the danger from frost will be lessened if the early spring growth be retarded. To irrigate the soil with *warm* water (which would afford the best protection) will tend to hasten the spring growth. On this account, the ground should be irrigated only when necessary for protection during the period when frost may occur.

The use of *cold* water in irrigating would render much less protection from frost, but would tend to delay the growth so that buds would not open until the frost season had passed.

DIRECTLY HEATING THE AIR BY MEANS OF FIRES.

Mr. Edward Copely's plan.—Mr. Edward Copely, of Riverside, Cal., in several articles published in the Riverside Press of April, 1896, describes at length experiments which he has made in heating the air directly by small fires of coal, placed in wire buckets hung a short distance above the ground. In his discussion, he takes into consideration the fact that on frosty nights the air for some distance above the ground is considerably warmer than the surface, consequently it would be possible to warm the lower air until its temperature and resulting density were equal to those of the air above the surface before there would be any tendency of the surface air to rise and escape. Therefore, he believes that it is possible, by means of small fires, to warm the lower stratum of air sufficiently to prevent frost and at the same time avoid loss of heat, which would result were there an upward draft of sufficient force to carry the heated air above the tree tops.

The difficulties experienced in all methods of directly heating the air arise from the unequal distribution of the heat through the lower portion of the air, on account of which the warmer masses of air rise above the region needing protection, and cold, denser air is continually flowing in from the sides to replace them. Of course, this upward draft will be less with small than with large fires.

During the winter of 1897–98 a number of unusually severe frosts occurred in the citrus region of California. Advantage was taken of these occasions by the Horticultural Club of Riverside to test many devices. Below is given an account of these experiments which were probably the most extensive and carefully conducted of any ever made in this country. These show very conclusively the value of these small fires in protection in such a dry climate as exists at Riverside. In fact this method proves the most satisfactory of all those tested, and a similar result will probably be found to be the case in places where the dew-point is 10° or more below the temperature of

the air at times of danger. From what the writer is able to learn he does not think the trials of the damp smudge were generally made in the most efficient manner; however, in very dry climates, the vapor of the wet smudge diffuses throughout the surrounding space without condensing, thus rendering that method of protecting inefficient.

REPORT OF EXPERIMENTS IN FROST PROTECTION MADE BY THE RIVERSIDE HORTICULTURAL CLUB DURING THE WINTER OF 1897–98.

Preliminary Report by E. W. Holmes and B. E. Wilhite.

Desiring to obtain reliable data as a guide to action by orchardists in preventing injury from frost, the Riverside Horticultural Club, after considerable discussion over the various theories presented, appointed a committee, of which J. H. Reed was chairman, to institute a series of practical experiments with the appliances made use of in the valley for that purpose.

Securing the assistance of an excellent corps of helpers, and carefully organizing the work to be done, Mr. Reed arranged for a thorough test of the different methods and fixed upon Saturday night for the first tests. It proved one peculiarly fit for the investigation.

Eight different plats were laid out, with a proper committee at each to make frequent observations during the night. In addition, five gentlemen were assigned the work of going over the whole ground to be able to make comparisons and qualify themselves to correctly judge of the details to be later furnished by the subcommittees. Professor Zumbro was of this committee, and made tests of humidity and temperature in and outside of the tracts where the different heat making processes were being carried on.

As the subject is one that demands prompt reporting, that the points gained may be made immediately available, I will anticipate the formal report, to be made to the Club when the data gained has been put in shape, and give to the public a few of the important results. The conclusions expressed are such as I have personally reached, and these may be in some degree modified upon a study of the figures to be furnished by the different committeemen.

The tests were made between Magnolia and Indiana avenues, in a section where the best opportunity is afforded for getting conditions as nearly as possible uniform, and were scattered over an area a mile and a half across.

In this section the mercury was 30° before the work commenced, at 2:30 in the morning, and in all the orchards was tending downward when operations began. Indeed, the night was much colder than was anticipated, and the temperature was near the danger point in a large portion of the valley before morning.

It gives me great pleasure to announce, as the result of the work of Saturday night, that henceforth there need be no serious loss of fruit in the average situation, where there is organized preparation on lines now demonstrated to be valuable.

It is not proper to give in detail before the committee's report is made public all the particulars of the study made, but I desire to state a few points regarding which I feel reasonably sure.

I do not feel certain that the experiment with moist straw burning demonstrated its value except as an adjunct to other methods. In the orchard where this was used there were excellent cypress wind-breaks, which helped materially in holding up the temperature. In this orchard the mercury stood uniformly 1° higher than in adjacent orchards, but I do not think it can be certain that the

smudge may have all the credit of this. The committee propose to give more thorough tests of this system before finally giving an opinion.

The steam apparatus of Mr. Hall, used near, and under similar local conditions, gave identical results with the straw test; but this test was not satisfactory, since a single machine could not be expected to change conditions over so large an area.

The steam apparatus on the navel orchard of Mr. Grant, the most complete of the kind yet used, did not raise either the dew-point or the temperature in the least. It is possible that if forty had been used instead of ten the result might have been different. But I am not inclined to believe success can be attained by this process. The truth is that the dew-point was not raised perceptibly, as was expected, and the cold increased until it reached the dew-point. The moisture settled and turned into frost on the leaves of the trees, and the temperature was not different after four hours' test from that in the open plain near.

But in the seedling orchard near, where twenty coal baskets to the acre were burning, we found the temperature 4° higher than in the navel orchard referred to. The tests showed that in seedling orchards near, where no work was being done, but where wind-breaks and the large trees themselves gave some protection, the mercury showed 2° more heat than in the navel grove, where the steam was generated, and this proved that the coal fires had raised the temperature at least 2°, enough in this case to absolutely insure safety.

On the Copley place the coal baskets were used, and only ten to the acre showed a difference of 1° early in the test, but later a difference of 2.5° over similar orchards adjacent.

I was skeptical about the value of this method when so few fires were lighted, but I now admit that the result shows this system deserving of general use, though I think not less than fifty baskets should be used if one would expect to increase the temperature sufficiently in a really cold spell to warrant effect.

But the test that gave the best result, and one so marked as to prove beyond all doubt the practicability of frost preservation, was that upon the Everest Ranch.

On the north line was a dense cypress row. On the east, from which direction came a drift of air of about 27° temperature, was placed a row of oil buckets, the fires being so near each other that the heat was very perceptible to one standing between them. Below them for several acres were burning oil pots, scattered some three rows apart each way. The trees were fair-sized navels, but not large enough to materially modify the temperature. A test near the row of fires on the windward side gave 32°. Several other tests in various parts of the area showed practically the same temperature, while 10 or 20 rods away 27° was indicated. Here was clearly a gain of 5° by artificial heating of "all out doors."

The oil fires were very hot and created a cloud of smoke very objectionable. But I could not but feel that coal baskets two or three times as numerous and arranged in the same way, with a massing of the fires to windward, would attain equal results, with less objection in the way of smut and less expense and trouble.

The section where a half acre was protected by a screen overhead showed 30°, and everything under it safe.

The water spray system gave no indication of increased temperature, the temperature being exactly the same as it uniformly was where no fires or smudges were made.

On Magnolia avenue, in the line of the drifting smoke, the mercury was 1° higher than where the fires and smoke had no influence.

I concluded from the above that our hope is in dry heat, rather than creating

artificial humidity, and for the first time feel confident that except in exceptionally cold sections the preservation of an orange crop, even in very cold winters, is possible. Respectfully yours,

E. W. HOLMES.

The following is a report from the effects of burning straw on the ranch of Dr. Baird, near the corner of Indiana avenue and Monroe street, between Monroe and Jackson. The firing was done by W. P. Legg and B. E. Wilhite of Arlington place. On Friday night, December 3, they burned on 10 acres 2 tons of straw, raising the temperature from 26° to 28°, on an average. On Saturday night, December 4, they burned three-quarters of a ton on the same 10 acres, raising the temperature from 28° to 29°, on an average.

On Sunday night, December 5, they burned 2 tons more, and the temperature ran from 24° to 26°, on an average. By placing the thermometer within a distance of 6 feet of the flame of straw the thermometer ran from 24° to 29°.

Now, if a little medicine will help a sick man, increase the dose and he will get well. If a little fire will warm you, more fire will make you sweat. There are, on an average, 10 flakes of straw to a bale, and 20 bales to the ton, or 200 flakes. Place one flake to a tree over your orchard, or a quarter of a ton to the acre, and at about 4 a. m. light them by pouring a little oil on the straw. It will take about 2 gallons to light 10 acres. When lighted, go over the orchard with a pitchfork and touch and relight what did not burn, and those that are burning stir up with the fork. By the time you get over the second time the sun is up and everything made safe. You are out $12 for straw, $4.50 for help to distribute the day before, which should always be done beforehand; $2.50 for lighting, and 32 cents for oil—or a total of $17.32 for each real cold night. If there are six such in one winter, you are out just $103.92, or about $10 per acre, and there are seldom over three nights of danger, and a crop worth $2,000 is saved for $103.92. This is a great thing, and the beauty of it all is that you scatter straw and ashes over your place, and of a cold winter your place is sufficiently fertilized and you are out comparatively nothing for frost protection. All the Riverside people should arrange for this and warm up the valley on the coldest nights. Coal is good, but you are out the expense of buying the baskets and placing them over the orchard and taking them in, and in the end get no fertilizer. I wish the people would look into this matter and do something that would make everyone happy.

B. E. WILHITE.

Final report of the committee of the Horticultural Club.

At the last meeting of the Riverside Horticultural Club the committee appointed to investigate the question of orchard protection made its report, which was adopted, as follows:

Your committee, appointed to investigate the subject of frost protection, has performed the duty assigned it, and herewith submits its report.

With the assistance of some fifteen or twenty citizens interested in the study of the points involved, a most complete test has been made of the many different methods employed to prevent frost damage. With such a force of competent and impartial observers, it was possible to secure data of much value in forming an estimate of the efficiency of the various plans made use of. Careful comparison was made between those orchards where no work was done, and where no direct effect of the fire was probable, and those where the different methods were being tried. As indicated by our partial report at the last meeting of the Club, these tests were in some particulars eminently satisfactory, as showing the way to definite conclusions.

The exceptionally long period of cold following gave additional opportunity to verify the first conclusions reached, and subsequent investigations made by ourselves, as well as by other citizens who have awakened to the possibility of protecting their property, strengthened and confirmed the opinion formed as the result of the tests already partially reported upon.

Some theories are proven to have little practical value, and members of your committee have modified their views somewhat in consequence. No preconceived notions have been allowed to stand in the way of a thoroughly practical study of the facts as they exist, to the end that the growers may not, for the lack of definite knowledge as to the direction their efforts should take, neglect reasonable precautions hereafter to insure the safety of their crops. These, therefore, are our conclusions:

First. There is no doubt whatever that the temperature of our orchards may be materially raised by the use of dry heat.

Second. The radiation of the earth's heat can be very considerably lessened by moist smudges, when these are started early enough and are properly managed.

Third. The possibility of raising the dew-point on one of the dry, cold nights peculiar to our climate, sufficiently to prevent damage, by means of steam-producing apparatus, seems impracticable.

Fourth. Fruit and trees can undoubtedly be saved, even in the coldest sections, by covering them with cloth or matting; but the expense involved makes this method impossible on the part of the ordinary grower.

Fifth. It is found that the temperature in an old seedling grove, or where tall wind-breaks afford to smaller fruit trees a like protection, the temperature is almost invariably 1° or 2° higher than in exposed orchards in the immediate neighborhood. This fact seems to thoroughly upset the theory, strongly held by many intelligent growers, that the tall, well-located wind-break is a disadvantage, the contrary seeming to be the truth.

Sixth. It is found that the temperature 20 feet above the ground is from 1° to 2° higher than at the surface, and that, as a rule, when the cold is severe enough to injure the ripest fruit, 50 feet from the ground there is almost invariably a temperature above the freezing point of water.

Professor Zumbro, who has given especial attention to this matter, finds that at the height of 50 feet the temperature is from 5° to 10° higher than at the surface when the air is not in motion. When there is any considerable breeze, it varies but little.

Seventh. Our conclusion is that, all things considered, the coal baskets, sufficiently numerous, will prove the most satisfactory and effective means of warming the orchards yet made use of. It is true, the oil pots make a far hotter fire, and are neither expensive nor difficult to manage; but the deposit of lamp black upon tree and fruit, resulting from their use, condemns this system for general use.

As to the value of smudging the members of your committee are not so well agreed. Because of less sharply defined results, we find it more difficult to come to definite, at least uniform, conclusions. But, under certain conditions, we are convinced that, properly used, it may be made a valuable means of protection. We think this especially true in localities where the temperature never falls but little below the danger point, and where there are considerable solid areas of young orchards exposed. Here it will work well if the protection is made general. But where the danger is considerable we think it wise to be prepared to use dry heat even where in connection with the smudge. The benefit from smudging is probably as much from its protecting fruit and trees from the sudden rays of the morning sun after a freezing night as from modifying temperature during the time of danger.

Experience demonstrates that flooding or running water in connection with dry heat or smudging is a valuable adjunct. One of the committee who has been testing this matter carefully for three years, is disposed to think that the direct benefit from running water is overestimated by the majority of growers. Its value in putting orchards in condition to withstand quite severe weather safely is unquestioned, but the committee are inclined to think that entire dependence upon this method will occasionally result in serious loss to those who trust to this means alone, especially when used in young orchards.

As to the number of baskets needed when coal is used, we find the most decided and satisfactory results have been gained where from twenty to fifty coal fires have been used to each acre. If intelligently and energetically used, this plan will never fail, except when the mercury drops below 24° for a long while, and even then it is believed the larger portion of the crop may be saved if anything like a general use of such fires be secured. The smaller number of fires named has, in numerous cases, and even when a man was working alone, secured a rise of from 3° to 5°, and saved a crop. Can it be doubted that fifty fires per acre, used in every orchard, would save both trees and crop on the coldest night ever known in California's history?

To equip an orchard with fifty baskets to the acre means an outlay of only a little over $5. The fuel to run them one night costs from $2.50 to $3. If a crop of navels upon it is worth $400 it will pay well to spend in fuel and labor $4 per night, or one per cent on the value of the crop to insure its safety. In the orange region of southern California it is not usual to have more than two or three nights in a season when the fruit is in danger. But even if, as in the present season, the period of cold is more extended, will it not pay to expend at least as much as one pays for his irrigating water to secure the safe maturing of a crop it has cost him a year's labor and heavy expense to produce?

The conclusion is obvious that we have only to provide for the insurance of this sort of property exactly as we would in the case of that liable to destruction by fire, to be enabled to follow the business of orange and lemon growing with the certainty of having perfect fruit to market at the season's end.

While the practicability of protecting our orchards from frost seems established, the problem of the most economical and scientific means of accomplishing this is probably yet to be solved. However well the wire baskets may serve us now, there doubtless will be improved methods for burning coal, and even other material may be found that will serve the purpose better, and while wet straw seems at present to be the most available for smudges, doubtless, when the need is made known, chemists will find some vapor-producing material more compact, efficient and economical. Hence we recommend that the Club appoint a permanent committee to continue these investigations.

Respectfully submitted,

J. H. Reed,
E. W. Holmes,
E. L. Koethen,
E. A. Zumbro,
J. H. Martin.

The following letter of Mr. E. W. Holmes, president of the Brocton Square (Riverside) Association, for preventing injury from frost, gives the results of some experiments made in November, 1896, at the same place, in which the damp smudge appeared to give the best results:

ORCHARD PROTECTION.

Impressions of a practical orchardist regarding the experiments made.

EDITOR PRESS: By request of several who were present at the experiments made upon the Meacham Ranch, I give you my impressions regarding the various tests of frost protection there made. I have had little opportunity to consult with others, and the opinions I may express are personal and such as are hastily formed from observation of the tests. The community is under obligation to the Meacham Brothers for affording an opportunity to study the different methods advocated for securing frost protection. They had arranged several rows of pots containing crude oil, over which were stretched wire netting, upon which was spread wet straw. Barrels of water were located conveniently, so as to keep the straw moistened. Upon another section of the orchard were rows of suspended wire baskets, each containing about 10 pounds of coal. There were apparently about twenty of these to the acre. In another row was an experiment with wet baled straw, in which fire was started by pouring kerosene upon it. Near this was a quantity of wet peat, ignited in the same way and used in connection with moistened straw.

The experiments made with the coal baskets have been so often described that no detailed reference is required. They were set on fire at about 5 o'clock, and were still burning at 8:30, without having required any special attention. The heat generated did not appreciably affect the temperature of the orchard, and the smoke was much less dense than that given off by the other fires. This is the method most easily handled, and by the saving of labor and definiteness of expense involved is most attractive to the orchardist who depends entirely upon his own exertions at the critical time. I am inclined to believe that a much larger number of baskets is required if these baskets are to be used alone. Whether the larger use will not involve expense equal to the other plans is a question. I think that it would be better not to increase the number, but to use them in conjunction with some steam-producing appliance.

The oil pots blazed up hotly when set going, and the flame, filtered through the dense moist straw or manure, set afloat a white cloud that drifted low through the orchard, and remained suspended among the trees until it had floated a long distance to leeward. Of the value of this method there can be no question; but the labor involved in keeping the straw properly wet, the pots from boiling over, or the fire from going out, is considerable. It is, also, in spite of the fact that the straw served as a filter and held an immense proportion of the lampblack, a dirty method for those engaged in the work.

The wet baled straw, while furnishing a less amount of heat and steam, required comparatively little attention. It is the cheapest of the three referred to, as the straw or stable bedding is not expensive, and if unused is worth all it costs as a fertilizer. Nearly every ranch affords the means for such a fog-producing method, and those who are deterred from assisting in a general effort, on account of the expense, are likely to give this a trial.

The experiment with the peat seemed to me hardly as satisfactory; but some better way of using it may be devised. It struck me that when saturated with water it is hardly more inflammable than a wet sponge, and that it could not be used the same as the wet straw, which smolders away even when thoroughly dampened. The cloud of moisture and smoke drifted for a mile or more down the valley, and showed no disposition to rise, as is the case when hot fires have been built.

The temperature in the orchard was not raised as much as I anticipated by the numerous fires, and this was at first discouraging. There was one point brought out, however, that deserves to be considered before one concludes that the

experiments failed of the success desired. And I am inclined to think those who are best posted in these matters will say that this point is the one upon which we may base our hope of success.

I found the trees in the center of the grove fairly dripping with moisture. Calling attention to this as an evidence of the good accomplished, a friend urged me to examine the trees outside of the area of the fires. I found that 10 rods distant, and not in the line of the drifted smoke, there was also moisture upon the foliage. But immediately upon reaching my own grove, a mile distant, ten minutes later, and before sunrise, I found the foliage everywhere absolutely dry. The mercury had not been raised in the grove appreciably by the many fires, but the question immediately occurred to me that I had discovered a result which might promise us security. If the thermometer had indicated 32° instead of 40°, and the general conditions were such as to send it to 26° without the use of the steam smudge, would not the presence of all this immense quantity of moisture in the atmosphere, produced by these local causes, so nullify the effects of the general condition as to preserve the tenderest fruit and foliage from freezing? I think it would. If not, then I am inclined to believe that no method at our command is of value.

I conclude, therefore, that no method is worth considering that does not include the generation of steam, and that whether we use coal, crude oil, or any other fuel, we need to join with it some plan that shall fill the air with moisture. This much seems to me to be demonstrated, and I confess that if this idea is not sound I am not sanguine of the success of any plan yet suggested.

The coal baskets are the easiest worked, and why can not a portion of them be so arranged by the placing of wet straw or manure above them upon a bit of corrugated iron as to use the coal in producing steam as well as heat.

In spite of the fact that the temperature was not raised as much as was anticipated by the numerous fires at this morning's experiment, the impression seemed general among those present that much had been gained by the morning's work, and that all that was needed to secure success was the united action of the growers.

The different conclusions arrived at in these two series of experiments made at the same place, and mainly by the same persons are probably in great measure due to the amount of moisture present. It is believed that when the air contains sufficient moisture, so that the amount added, by vapor-producing methods, will cause condensation of moisture and deposit of dew at a temperature above the point of injury, then that method will be found efficient. This will probably be the case when the difference between the readings of a common thermometer with a dry bulb and one with the bulb covered with a thin layer of moist muslin is but 3° or 4°. The coal baskets will prove the more efficient the greater the difference between the temperature of the air 5 feet above the ground and at the tree tops. Unless the temperature at the height of the tree tops is 2° or 3° warmer than at the height of the lower limbs little benefit is to be expected. The smaller the fires and the greater number to the acre, the greater the protection for the same amount of fuel.

IV. DRAINING THE COLD AIR FROM THE REGION NEEDING PROTECTION.

Mr. J. E. Cutter, in the Riverside Press of January 18, 1896, pub-

lished several articles on the subject of "Frost Protection." In these articles he called attention to the fact that on frosty nights the radiation cools the air near the surface, which increases its density and causes it to flow down the hillside and through the valley in a manner similar to the flow of water on sloping surfaces. This cold air collects in the lowest portion of the valley and slowly submerges the trees, frequently causing killing frost in such a location, while no injury results to the trees on the surrounding hills. He suggests warming the air by large bonfires. This may be feasible. Such fires should be placed at the lowest portion of the valley. They will draw into them the cold air near the surface, which will then be heated and pass upward, thus keeping up a continuous draft of the cold air toward the fire. It is very doubtful if better protection might not be obtained by the expenditure of the same fuel in small smudge fires.

Air drainage.—It may be possible, in many instances, to permanently remove or greatly diminish the danger arising from the flow of cold air down the hillside into the valley by constructing windbreaks, so placed as to drain off this cold air from the locality. The breaks could be in the form of a high, closed fence or levee. Preferably there should be a levee 4 or 5 feet high, with the ditch on the side next the hill, into which, if possible, water should be turned. On the top of the levee a closed fence should be placed. The evaporation of the water from the stream would tend to raise the dew-point of the air. The levee should be so placed along the slope near its base as to intercept the cold air and lead it beyond or around the orchard. It should have a continuous slope downward, the steeper the better, so that the cold air will not overflow it.

V. MIXING THE AIR SO AS TO PREVENT THE COLD AIR FROM SINKING TO THE SURFACE.

While many of the preceding methods depend partly on this principle for their success, the writer is not familiar with any process which depends solely upon it.

WHEN AND HOW TO PROTECT.

The experience of the past two seasons has shown that forecasts of sudden and decided changes in temperature over a large territory are among the most accurate made by the Weather Bureau; consequently, it is reasonable to expect that, if suitable arrangements are made, warnings may be received of those otherwise unexpected cool waves which will result in frost. There are instances, however, when the general forecasts of the Weather Bureau can not be expected to be sufficiently specific to provide for the different conditions that may prevail in various sections. The temperature frequently remains for several days near the critical point, and a change of a very few degrees

or a local clearing or clouding of the sky will cause or prevent injury. Again, the conditions in certain localities are such as to make them more susceptible to frost than the surrounding region. Prof. Willis L. Moore, Chief of the Weather Bureau, states that, while forecast official in Wisconsin, he observed that a frost occurring immediately after a rain was not as injurious as when the ground and plants were dry. It is therefore necessary that the orchardist and gardener be able to judge, at times, for themselves when danger from frost is imminent. For this purpose they should be provided with a wet and dry-bulb hygrometer, by which can be determined the dew-point of the air or the temperature at which condensation takes place. Condensation checks the fall in temperature on frosty nights. Frequent observations with this instrument should be made.

If, in the afternoon, the dew-point is near the critical temperature, arrangements should be made for protecting, if necessary. If, at a later hour, the dew-point is constant or lower, the sky clear or clearing, and the air calm, it is reasonable to expect that the temperature will fall to the dew-point during the night. The efforts to protect should be based on this dew-point. If it merely approximates the danger point (and no warning of more severe temperatures has been received) but little protection will be necessary, and action may be delayed until the temperature is but a few degrees above the danger point. However, if the dew-point be several degrees below that liable to cause injury, or if it be falling, or if a change for the colder be anticipated, efforts to protect should be undertaken earlier.

No specific rules of universal application can be laid down for the guidance of the orchardist in protecting. The same intelligent, careful, and systematic attention must be given to this as to other subjects in order to secure success. However, the following suggestions may be of value:

Irrigation should be resorted to wherever possible. The water should be turned on during the day preceding the night when frost is anticipated, and continued until the ground is thoroughly saturated.

In all sections it is recommended that either coal baskets or some method for causing a wet smudge be used, or a combination of both. The coal baskets will be found the more useful the drier the air and the greater the excess in temperature 30 or 40 feet from the ground, and near the surface, as previously explained. For the purpose of determining this difference a pole 40 or 50 feet long, with halyards, like a flagstaff, should be erected in the orchard. Two thermometers should be attached to the halyards, so that as one thermometer is at the top of the pole the other is 5 feet from the surface. Leave one thermometer at the top of the pole for five minutes; read the one near the ground, and then quickly lower and read the one which has been at the top of the pole.

When coal baskets are used there should be from twenty-five to fifty of them used to the acre, depending on the intensity of cold, as described in the reports of the Horticultural Club of Riverside. When the wet smudge is used probably better results would be obtained from a combination of the portable and stationary smudges. About one wagon or sled, arranged for carrying an evaporating fire, should be provided for each 50 acres. In addition, stationary smudges should be used. The material for these should be prepared at the beginning of the frost season, and kept in readiness for immediate use. Sacks filled with wet manure or bales of wet straw should be distributed throughout the orchard. The sacks should be placed about 75 feet apart each way, at the intersection of the rows. A smaller number of bales of straw is necessary. Hollows should be dug a few inches deep about each sack, and, if the sack becomes dry before being used, a pailful of water should be poured upon it, which will remain in the hollow near the sack until absorbed. Whenever it is necessary to protect, an effort should be made to determine the direction in which the air drifts across the orchard. And the sacks should be fired in rows running *across* this draft, beginning at the windward side of the orchard. Every sack should be ignited in the row, but only every third or fourth row need be burned the first night; the remainder being available for succeeding nights. In setting fire to the sacks, one man goes ahead with a pail of coal-oil and pours about a pint on each sack; and another, following with a torch, ignites them. In the meantime, portable smudges should be put in operation. They should be driven forward and back between the rows and across the drafts of the orchard. It is very desirable, if not essential, that the superintendent take a position on the most elevated point at his command, as the top of a house, barn, water tank, or windmill, from which he can observe the drift of the smudge and direct the movement of the teams so as to secure the best results.

It would seem that these precautions should be sufficient to prevent injury, unless it be in the case of narrow valleys, where the cold air from the unprotected hillsides displaces that which has been kept warm, and, should wind-breaks be found successful in removing this danger, it is believed there are few, if any, localities where injury could not be avoided.

It is evident that in attempting to protect one ranch the owner will, in a measure, protect his neighbor; therefore, if some arrangements for cooperation among the individuals in the same locality were made, the greatest protection could be provided at the minimum expense. By such a cooperation of all the residents of the valley, a system of wind-breaks or air-drainage dikes (if found valuable) could be laid out and built in such a manner as to result in the greatest general good at the least cost. Arrangements could be made which

would insure the distribution of a frost warning from the Weather Bureau throughout the entire district. Some person, provided with a telephone, could receive the warnings from the Bureau, and, in turn, telephone them to all others having such instruments. All so receiving them could display the frost signal, and thus the warning would be quite generally distributed.

Some person in each locality or ranch should study the peculiarities of his section. He should thoroughly understand the conditions under which frost forms, should provide himself with a psychrometer, and take frequent observations on afternoons and evenings when frost is imminent, and thus be enabled to give the most accurate information possible to his locality. He would probably thus prevent the inconvenience and expense connected with protecting when the local conditions or a change in the weather were such as would prevent a frost, and also he would be likely to discover times when frost was imminent when no warning had been received. This man, indeed, should be a sort of local expert on this subject.

The following notes on frost protection for citrus fruits at Riverside (being the individual report of Mr. E. L. Koethen, a member of the Frost Protection Committee of the Riverside Horticultural Club, and secretary of the club) are so excellent and many are of such general application that their perusal is recommended to all:

1. In sections where there is a prevailing draft from a certain direction concentrate the fires somewhat on the sides of the orchard from which this draft comes.

2. Some fires are needed all through the orchard.

3. If the thermometer should reach 26° by midnight, start firing at once. If smudging is to be depended upon, you should commence much earlier. To be safe, commence lighting baskets, if the thermometer should reach 26°, as late as 4:30 a. m.

4. Ripe fruit will stand more frost than green fruit. The above figures are for ripe fruit.

5. The thermometer may go many degrees below the dew-point in our climate on nights when the sun sets behind heavy clouds.

6. A mild day may be followed by a night of danger to citrus fruits.

7. The upper strata of air are much warmer than the lower. Eight degrees was found to be the variation between a height of 5 and 50 feet, upon different tests.

8. Thermometers should be tested each year, and the variation noted and accounted for at each reading.

9. A good way to secure uniform observations and the extreme temperature to which fruit is exposed is to fasten the thermometer to a slender stick 5 feet long and place in the space between four trees, away from buildings or other shelter.

10. Every grove has some spot that is colder than any other. Find it, and be governed in your firing by the temperature there, keeping your eye on other locations, for the coldest place may shift around.

11. A thermometer that registers too high may be very comforting, but is not a safe guide unless allowance is made for correction.

12. A thermometer that registers too low may cost unnecessary labor, expense, and anxiety.

13. We need a united system of general alarm for localities throughout the valley.

14. Wind-breaks, parallel with the flow of the cold stream of air, are an advantage in preventing radiation.

15. Close wind-breaks, at right angles to the flow of cold air, will form dams and cause low temperatures on the upper side. A block of large trees below a block of smaller trees will have the same effect.

16. Coal baskets or brush fires concentrated at these points will drain off the cold air.

17. Flowing water is a help, but is not sufficient in itself.

18. Clean culture and a wet surface is the best condition of the soil in times of danger.

19. Trees that had suffered from lack of water at any time during the development of the crop and those with a dry surface of the soil suffered greatest injury.

20. Firing of any kind is beneficial if there is enough of it.

21. The cost need not be prohibitive for good results.

22. Accumulative firing is better than single-handed.

23. A single grower can succeed in saving his fruit with coal baskets if he has enough of them.

24. Be prepared to make more fires than you will likely need. The unexpected sometimes happens.

25. No grower should depend on his neighbors for heat or smudge. Every gap is an injury to the whole. Besides, your neighbors may not locate their fires so as to do you much good.

26. Coal baskets can be made for about 7 cents each. The filling will cost about 7 cents, where bituminous coal costs $10 per ton, and you should have from twenty-five to fifty per acre, according to location and size of grove.

27. A little burning straw is a snare and deceit.

28. Straw smudge should be made from wet straw, should be dense, and should cover large areas to yield best results. Dry straw is of little value, except to help burn that which is very wet.

29. The efficacy of smudging being dependent upon preventing radiation in very dry climates, early lighting in such cases is imperative.

30. A little dry brush is a great help in burning very wet straw.

31. Green cypress boughs create a fine smudge.

32. Most groves have a cold corner. Have some brush piles ready to light at the critical hour—about dawn.

33. Coal baskets should be full at the start. Coal will not ignite readily in replenishing if a good bed of coals is not secured at first. A reserve supply of coal may be very useful if the cold is long continued.

34. Coal baskets need less attention than the smudge.

35. Have plenty of help. The better your fires are tended, the better the results.

36. But few employees can be depended upon to look after the details and carry on the work. *Your personal attention is needed.*

37. Every detail should be prepared beforehand. There is no time to hunt up torches and tools after the danger point is reached.

38. Oil fires will do good work, but the smut is objectionable.

39. Evaporating pans give no visible results.

40. An awning or cover was found to be of great service.

It may be believed that the trouble and expense necessary to carry

out these plans are greater than the benefits accruing from the protection, but this seems hardly true, as a general rule. The supplies needed in the various methods are inexpensive, straw, manure, old rubbish, prunings, etc., being excellent materials for fuel. A few old sacks and cheap sleds are the principal apparatus. The most essential supply is water. Coal baskets cost but about 10 cents a piece, and the necessary fuel for a night costs but from 1 to 5 cents, according to price of coal. Successful protection was accomplished during several nights last year, in many sections, at an expense of less than 1 per cent of the value of the crop. Really, the trouble, inconvenience, and labor, are practically the only drawbacks, while the gain may amount at times to many thousand dollars.

APPENDIX No. 1.

THE USE OF THE SLING PSYCHROMETER.

This instrument is a form of hygrometer most suitable for the use of the orchardist. It consists of two thermometers fastened to the same back and arranged for whirling. One of the thermometers has its bulb covered with thin muslin, moistened with water. The evaporation of the water about the wet bulb lowers the temperature and causes this thermometer to read lower than the one with a dry bulb. From the difference between these readings and the temperature of the air itself the dew-point can be quite accurately determined from the accompanying table.

Exposure.—While the psychrometer will give quite accurate indications, even in the bright sunshine, yet observations so made are not without some error, and where greater accuracy is desired the psychrometer should be whirled in the shade of a building or tree, or, as may sometimes be necessary, under an umbrella. In all cases there should be perfectly free circulation of the air, and the observer should face the wind, whirling the psychrometer in front of his body. It is a good plan, while whirling, to step back and forth a few steps, to further prevent the presence of the observer's body from giving rise to erroneous observations.

The wet bulb.—It is important that the muslin covering for wet bulb be kept in good condition. The evaporation of the water from the muslin leaves always in its meshes a small quantity of solid material, which, sooner or later, somewhat stiffens the muslin, so that it does not readily take up water. This will be the case if the muslin does not readily become wet after being dipped in water. On this account it is desirable to use as pure water as possible, and also to renew the muslin from time to time. New muslin should always be washed to remove sizing, etc., before used. A small rectangular piece, wide enough to go about one and one-third times around the bulb and long enough to cover the bulb and that part of the stem below the metal back, is cut out, *thoroughly wetted* in clean water, and neatly fitted around the thermometer. It is tied first around the bulb at the top, using a moderately strong thread. A loop of thread to form a knot is next placed around the bottom of the bulb, just where it begins to round off. As this knot is drawn tighter and tighter the thread slips off the rounded end of the bulb and neatly stretches the muslin covering with it, at the same time securing the latter at the bottom.

To make an observation.—The so-called wet bulb is thoroughly saturated with

water by dipping it into a small cup or wide-mouthed bottle. The thermometers are then whirled rapidly for fifteen or twenty seconds; stopped and quickly read. A mental note of the readings is made, when they are again whirled and read. This will be continued until the wet-bulb thermometer ceases to fall, when the readings of the two thermometers should be read and recorded. If the wet thermometer should read 32°, the whirlings and frequent readings should be continued for a considerable time, to be certain that a further fall will not take place. The freezing of the water at 32° causes the fall to be checked for a short time.

Subtract the reading of the wet thermometer from that of the dry. Find this difference in the line at the top of the table. The dew-point will be found at the intersection of the column beneath with the line which has the proper dry thermometer reading at the left.

First example.

Dry-bulb thermometer	55°
Wet-bulb thermometer	44
Difference	11
Dew-point from table	30

Second example.

Dry-bulb thermometer	43°
Wet-bulb thermometer	38
Difference	5
Dew-point from table, between 28° and 33°, about	30

Dew-point table—Fahrenheit temperatures.

t (Dry ther.)	Difference between the dry and wet thermometers ($t—t'$).																				$t.$ (Dry ther.)
	1°	2°	3°	4°	5°	6°	7°	8°	9°	10°	11°	12°	13°	14°	15°	16°	17°	18°	19°	20°	
20	17	13	8	2	−6	−19															20
21	18	14	9	4	−4	−15	−47														21
22	19	15	11	6	−1	−11	−31														22
23	20	16	12	7	+1	−8	−24														23
24	21	18	14	9	3	−5	−18														24
25	22	19	15	11	5	−2	−13	−42													25
26	23	20	16	12	7	0	−9	−28													26
27	24	21	18	14	9	+3	−6	−20													27
28	25	22	19	15	11	5	−3	−15	−54												28
29	26	24	20	17	12	7	0	−10	−32												29
30	27	25	22	18	14	9	+2	−6	−22												30
31	29	26	23	19	15	11	5	−3	−15												31
32	30	27	24	21	17	13	7	0	−10	−33											32
33	31	28	25	22	18	14	9	+3	−6	−22											33
34	32	29	26	24	20	16	11	6	−2	−15											34
35	32	30	28	25	22	18	13	8	+1	−9	−32										35
36	34	31	29	26	23	19	15	10	4	−5	−20										36
37	35	32	30	27	24	21	17	12	6	−2	−14	−52									37
38	36	33	31	28	26	22	19	14	9	+2	−8	−29									38
39	37	34	32	29	27	24	20	16	11	5	−4	−18									39
40	38	35	33	30	28	25	22	18	13	8	0	−12	−44								40
41	39	36	34	32	29	26	23	20	15	10	+4	−6	−25								41
42	40	38	35	33	30	27	24	21	18	12	7	−2	−15								42
43	41	39	36	34	31	29	26	23	19	14	9	+2	−8	−33							43
44	42	40	37	35	32	30	27	24	20	16	12	6	−4	−19							44
45	43	41	39	36	33	31	28	25	22	18	13	8	0	−11	−48						45
46	44	42	40	37	35	32	30	27	24	20	16	11	+4	−5	−24						46
47	45	43	41	39	36	33	31	28	25	22	18	13	7	−1	−14						47
48	46	44	42	40	37	35	32	29	26	23	20	15	10	+2	−8	−30					48
49	47	45	43	41	38	36	33	31	28	25	21	17	12	6	−3	−18					49
50	48	46	44	42	40	37	34	32	29	26	23	19	14	9	+1	−10	−42				50
51	49	47	45	43	41	38	36	33	31	28	24	21	17	11	5	−5	−22				51
52	50	48	46	44	42	40	37	34	32	29	26	23	19	14	8	0	−13				52
53	51	49	47	45	43	41	38	36	33	30	28	24	20	16	11	+4	−6	−28			53
54	52	50	49	46	44	42	40	37	34	32	29	26	22	18	13	7	−2	−16			54
55	53	52	50	48	46	43	41	39	36	33	30	28	24	20	16	10	+3	−8			55
56	54	53	51	49	47	44	42	40	37	34	32	29	26	22	18	13	6	−2	−19		56
57	55	54	52	50	48	46	44	41	39	36	33	30	28	24	20	15	10	+2	−10	−48	57
58	56	55	53	51	49	47	45	42	40	37	35	32	29	26	22	18	12	6	−3	−22	58
59	57	56	54	52	50	48	46	44	41	39	36	33	31	27	24	20	15	9	+1	−12	59
60	58	57	55	53	51	49	47	45	43	40	38	35	32	29	26	22	18	12	5	−5	60
61	59	58	56	54	52	50	48	46	44	42	39	36	33	31	28	24	20	15	9	0	61
62	60	59	57	55	53	52	50	48	45	43	41	38	35	32	29	26	22	18	12	+5	62
63	61	60	58	56	55	53	51	49	47	44	42	39	37	34	31	28	24	20	15	9	63
64	62	61	59	57	56	54	52	50	48	46	43	41	38	35	32	29	26	22	18	12	64
65	63	62	60	59	57	55	53	51	49	47	45	42	40	37	34	31	28	24	20	15	65
66	64	63	61	60	58	56	54	52	50	48	46	44	41	38	35	32	30	26	22	18	66
67	66	64	62	61	59	57	55	54	52	50	47	45	43	40	37	34	31	28	24	20	67
68	67	65	63	62	60	58	57	55	53	51	49	46	44	42	39	36	33	30	26	23	68
69	68	66	64	63	61	59	58	56	54	52	50	48	46	43	40	38	34	32	28	25	69
70	69	67	66	64	62	61	59	57	55	53	51	49	47	45	42	39	36	33	30	27	70
71	70	68	67	65	63	62	60	58	56	55	53	51	48	46	43	41	38	35	32	29	71
72	71	69	68	66	64	63	61	59	58	56	54	52	50	47	45	43	40	37	33	31	72
73	72	70	69	67	66	64	62	61	59	57	55	53	51	49	46	44	41	38	35	32	73
74	73	71	70	68	67	65	63	62	60	58	56	54	52	50	48	45	43	40	37	34	74
75	74	72	71	69	68	66	64	63	61	59	57	56	54	52	49	47	44	42	39	36	75
76	75	73	72	70	69	67	65	64	62	61	59	57	55	53	50	48	46	43	41	38	76
77	76	74	73	71	70	68	67	65	63	62	60	58	56	54	52	50	48	45	42	40	77
78	77	75	74	72	71	69	68	66	65	63	61	59	57	55	53	51	49	47	44	41	78
79	78	76	75	73	72	70	69	67	66	64	62	61	59	57	55	53	51	48	46	43	79
80	79	77	76	74	73	72	70	68	67	65	63	62	60	58	56	54	52	50	47	45	80
$t.$	1°	2°	3°	4°	5°	6°	7°	8°	9°	10°	11°	12°	13°	14°	15°	16°	17°	18°	19°	20°	$t.$

APPENDIX NO. 2.

INJURIOUS TEMPERATURES.

Table of temperatures at which the following plants are liable to receive injury from frost, compiled from information received from horticulturists, orchardists, and gardeners throughout the entire Pacific coast.

The temperatures given are, as nearly as possible, those of the air in contact with the plant itself.

Plants or fruits.	In bud.	In blossom.	In setting fruit.	At other times.	Plants or fruits.	In bud.	In blossom.	In setting fruit.	At other times.
	°	°	°	°		°	°	°	°
Almonds	28	30	30	28	Onions	......	......	......	29
Apples	27	29	30	26	Oranges†	30	31	31	‡26 §29
Apricots	30	31	32	30	Parsnips	......	......	......	27
Asparagus	29	29	29	26	Peaches	29	30	30	29
Bananas	31	31	32	31	Pears	28	29	29	28
Barley	......	29	......	.....	Peas	29	30	30	25
Beans	......	31	......	......	Plums	30	31	31	29
Beets	......	......	......	25	Potatoes:				
Cabbage	......	......	......	15-27	Irish	30	30	30	31
Cantaloupes	32	32	......	30-31	Sweet	31	31	31	31
Cauliflower	......	.....	......	20-27	Prunes	30	31	31	29
Celery	......	......	......	28	Radishes	......	......	......	25
Cucumbers	31	31	31	32	Shrubs, roses, or trees.	26-30	28-32	.....	30-26
Cymlings or squash	31	31	31	30	Spinach	......	......	......	21
Flowers*	31	31	31	30	Strawberries	28	28	28	30
Grapes	31	31	30	28	Tangerines	31	31	31	28
Grape fruit	30	31	31	28	Tomatoes	31	31	31	31
Lemons	30	31	31	28	Turnips	......	......	......	26
Lettuce	......	.....	......	12-28	Watermelons	......	......	......	28-31
Mandarins	31	31	31	28	Wheat	......	31	31	......
Oats	31	......	......	......	Walnuts, English	30	31	31	28
Okra	......	......	......	31					
Olives	30	31	31	‡18 §24					

* Depends on variety. † Injured at 2° higher if continued four to six hours. ‡ Ripe. § Green.

○